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RESEARCH MEMORANDUM

for the

U. S. Air Force

FREE-FLIGHT-TUNNEL INVESTIGATION OF THE STABILITY AND CONTROL OF A REPUBLIC F-84E AIRPLANE TOWED BY A SHORT TOWLINE

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON

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FREE-FLIGHT-TUNNEL INVESTIGATION OF THE STABILITY AND CONTROL OF A REPUBLIC F-84E AIRPLANE TOWED BY A SHORT TOWLINE

By Robert E. Shanks

SUMMARY

As part of a study to determine the feasibility of using a combination of the Consolidated Vultee RB-36 and Republic F-84E airplanes for long-range reconnaissance missions (project FICON) an experimental investigation has been conducted in the Langley free-flight tunnel to determine the stability and control characteristics of a fighter airplane in several tow configurations proposed for launching and retrieving the F-84E. The model used in the tests approximately represented a 0.07-scale model of the F-84E airplane. The investigation consisted of flight tests in which the model was towed from a strut in the tunnel.

At towline lengths of about 20 feet (full scale) the model had a very unstable lateral oscillation which could not be controlled. Neither a roll damper which increased the damping in roll to about twice its normal value, nor a yaw damper which increased the damping in yaw to about six times its normal value caused any appreciable improvement in the stability or controllability of the lateral oscillation. For towline lengths from about 1 to 5 feet (full scale) the lateral oscillation was unstable, but could be stabilized by use of the yaw damper. The longitudinal motion, however, was an unstable short-period pitching oscillation which could not be controlled by the pilot.

For the zero-towline case where the model was directly coupled to the strut with complete angular freedom, the longitudinal stability was good in all the configurations covered in the tests. In the basic condition the lateral oscillation was very unstable and the model could not be controlled. The lateral stability could be improved by use of either the yaw damper or spring restraint in roll. Increasing the moments of inertia was found to have a destabilizing effect but, with the strong roll spring and the yaw damper used together, the lateral oscillation was stable for all the inertia conditions covered in the tests. Neither the addition of the roll damper nor use of an alternate tow attachment position resulted in any significant change in the lateral stability or controllability of the model.

INTRODUCTION

The U.S. Air Force has undertaken a program (project FICON) to determine the feasibility of using a Republic F-84F airplane as a parasite in combination with a Consolidated Vultee RB-36 in order to extend the range of the fighter for high-speed reconnaissance. One part of this program is the development of a satisfactory method for launching and retrieving the parasite which in the preliminary tests will be an F-84E airplane. In the proposed method, a 20-foot tow cable is trailed from a trapeze extending from the bomb bay of the bomber. The fighter approaches the bomber from the rear and inserts a probe into a drogue on the end of the trailing cable. The cable is completely reeled in so that the fighter is at the trapeze. The fighter is then locked to the trapeze which draws it up to its stowed position in the bomb bay. The Air Development Force has requested the Langley free-flight tunnel to conduct an experimental investigation of the stability and control characteristics of the fighter airplane in several tow configurations in order to facilitate the full-scale flight tests planned by the Consolidated Vultee Aircraft Corporation.

In order to expedite the investigation, a simplified model was used to represent the F-84E airplane because such a model was already on hand at the time of the request and provided a reasonable approximation of the F-84E. The model was towed from a strut in the tunnel and the lateral and longitudinal stability and controllability were studied for a range of towline lengths from 0 to 20 feet, full scale. The effects of mass distribution, artificial damping in yaw, artificial damping in roll, and towline attachment location were investigated for all towline lengths. For the case of zero towline length in which the model was coupled directly to the strut with complete angular freedom, the effect of spring restraint in roll was also determined. The use of a rigid strut instead of a model of the bomber was felt to be justified because of the large difference in relative sizes of the two airplanes; that is, the motions of the bomber arising from the fighter motions will be relatively small, so that the assumption that the bomber maintains steady flight should give a reasonable first approximation to the actual fighter motions.

SYMBOLS

All the forces and moments are referred to the stability system of axes which are defined and illustrated in figure 1.

I_X moment of inertia of model about X-body axis, slug-ft^2

I_Y moment of inertia of model about Y-body axis, slug-ft^2

I_Z moment of inertia of model about Z-body axis, slug-ft^2

S wing area, sq ft

b wing span, ft

V airspeed, fps

ρ mass density of air, slugs/cu ft

q dynamic pressure, lb/sq ft

C_L lift coefficient, Lift/qS

C_D drag coefficient, Drag/qS

C_Y lateral-force coefficient, Lateral force/qS

C_l rolling-moment coefficient, Rolling moment/qS

C_n yawing-moment coefficient, Yawing moment/qS

φ angle of roll, deg

θ angle of pitch, deg

β angle of sideslip, deg

p rolling angular velocity, radians/sec

r yawing angular velocity, radians/sec

C_{l_β} rate of change of rolling-moment coefficient with angle of sideslip in degrees, $\partial C_l/\partial\beta$

C_{n_β} rate of change of yawing-moment coefficient with angle of sideslip in degrees, $\partial C_n/\partial\beta$

C_{Y_β} rate of change of lateral-force coefficient with angle of sideslip in degrees, $\partial C_Y/\partial\beta$

C_{n_r} rate of change of yawing-moment coefficient with yawing-angular-velocity factor, $\dfrac{\partial C_n}{\partial \frac{rb}{2V}}$

C_{l_p} rate of change of rolling-moment coefficient with rolling-angular-velocity factor, $\frac{\partial C_l}{\partial \frac{pb}{2V}}$

C_{l_r} rate of change of rolling-moment coefficient with yawing-angular-velocity factor, $\frac{\partial C_l}{\partial \frac{rb}{2V}}$

C_{n_p} rate of change of yawing-moment coefficient with rolling-angular-velocity factor, $\frac{\partial C_n}{\partial \frac{pb}{2V}}$

MODEL

As pointed out previously, an existing simplified model was used to represent the Republic F-84E airplane in order to expedite the model tests so that they could be completed before the full-scale flight testing was begun. A photograph of the model which was used to represent the F-84E airplane is presented in figure 2 and sketches of the model are presented in figure 3. Figure 3(a) is a three-view drawing showing the principal dimensions. The two tow attachment points located on this drawing are the design and alternate locations chosen by the Consolidated Vultee Aircraft Corporation. The model was considered as approximately a 0.07-scale model of the F-84E airplane since that was the scale of the wing area. Figure 3(b) shows a comparison of the test model with an 0.07-scale model of the airplane to indicate how closely the model represented the airplane with regard to its other geometric characteristics.

A comparison of the aerodynamic parameters of the test model with those of the F-84E airplane is presented in table I. The values for the F-84E airplane were obtained from the static-force-test results presented in reference 1 and by estimation using the methods of reference 2. The values for the test model were obtained from force tests made in the free-flight tunnel and by estimation procedures similar to those used for the airplane.

With the exception of C_{n_r}, the derivatives are in reasonably close agreement so that the dynamic stability characteristics of the test model would not be expected to be greatly different from those of the F-84E airplane except for the effect of the difference in the values of C_{n_r}. The rather large difference in the values for the important lateral stability parameter C_{n_r} undoubtedly caused the test model to have somewhat less stability than the F-84E. Some indication of the effect of this difference may be obtained from the lateral behavior of the model at the two values of C_{n_r} (with and without the yaw damper).

APPARATUS AND TESTS

The investigation consisted of tow tests in the Langley free-flight tunnel which is described in reference 3. The test airspeed was about 52 miles per hour which corresponds to an airspeed of about 200 miles per hour at sea level for an F-84E airplane. The lift coefficients for these tests varied from about 0.55 to about 0.70 depending upon the loading of the model.

The model was towed from the lower end of a strut which extended downward from the top of the tunnel test section. The towline used was a $\frac{1}{16}$- inch-diameter $\left(\frac{7}{8}\text{- inch-diameter, full scale}\right)$ cotton line. The length of the line could be varied from outside the test section during a test. Tests were made at various towline lengths through a range from 0 to 17 inches which corresponded to full-scale lengths of 0 to 20 feet.

The strut and apparatus used to represent the launching and retrieving trapeze on the Consolidated Vultee RB-36 for the zero-towline-length tests are shown schematically in figure 4. A direct coupling which provided complete angular freedom was used to connect the model to the strut. The coupling consisted of a universal joint which provided freedom in pitch and yaw. No attempt was made to simulate the flexibility of the full-scale trapeze in pitch or yaw; that is, the trapeze was assumed to be rigid in these respects. The universal joint was mounted in a ball bearing in such a way that it was free in roll about the X-wind axis but could be restrained in roll by a torsion spring. Two springs were used in the tests to provide roll restraints which were equivalent to full-scale values of about 100,000 and 200,000 foot-pounds per radian. The weaker spring approximately represented the torsional flexibility in roll of the full-scale trapeze.

The model was tested in the three loading conditions given in table II. The loading conditions represent the airplane with wing-tip tanks off (condition I) and with two wing-tip tank configurations with different amounts of fuel (conditions II and III). In this table the model mass characteristics are presented in terms of scaled-up weights and moments of inertia for direct comparison with the characteristics of the F-84E airplane.

In most of the tests the ailerons alone were used for lateral control as a matter of convenience. Preliminary tests showed that the use of linked rudder and aileron control did not provide appreciably better control than did the ailerons alone. The model was equipped with a rate-gyro automatic stabilizing device to increase either the damping in roll (roll damper) or the damping in yaw (yaw damper). This device consisted of a rate gyro which controlled a pneumatic servoactuator that operated the ailerons to increase the damping in roll or the rudder to increase the damping in yaw. By means of this system the damping in roll could be artificially increased to about two times the normal value for the model and the damping in yaw could be increased to about six times the normal value for the model.

RESULTS AND DISCUSSION

The results of the tests are presented in the form of the pilot's observations of the controllability of the model and in the form of film records of the uncontrolled rolling and pitching motions of the model. The test results are presented in figures 5, 6, and 7 for the 20-foot-towline, 5-foot-towline, and direct-coupling configurations, respectively.

A motion picture containing film records of the flight behavior of the model in all the test configurations discussed herein is available on loan from the NACA Headquarters, Washington, D. C. The results of this investigation are illustrated more graphically by the flight scenes of this motion picture than is possible in the present paper.

Towline Tests

20-foot towline.- The model was found to be very unstable laterally and could not be controlled in any of the configurations tested with the 20-foot (full scale) towline. These results are in qualitative agreement with the theoretical calculations given in reference 4 which predict a very unstable lateral oscillation. The motions presented in figure 5 show that neither increasing the damping in roll to twice its normal value, nor moving the tow attachment point back to the alternate position had any appreciable effect on the rolling motions. No comparable records were obtained for the configuration in which the damping in yaw was six times the normal value, but visual observation indicated that the yaw damper did not effect any significant improvement in the behavior of the model. The pilot was unable to control the lateral motions of the model in any of the test configurations for more than a few seconds because of the short period (about 1 second) and large degree of instability. It might be possible to control this motion in the case of the full-scale fighter, however, since the period of the oscillation would be about 4 seconds. The behavior of the fighter might be improved by use of power to reduce the tension in the tow cable because the restraint of the towline is responsible for the instability; in effect the stability characteristics of the fighter on tow approach those of the unrestrained fighter as the thrust increases. No longitudinal instability was evident but the model could have had considerable instability which was masked by the very violent lateral behavior of the model.

<u>1- to 5-foot towline</u>.- A few tests were made throughout the towline length range from 0 to 20 feet (full scale) which showed that at towline lengths up to about 1 foot (full scale) the model behavior was the same as that at 0 and at towline lengths greater than about 5 feet (full scale) the behavior approached that described previously for the 20-foot-towline case. At very short towline lengths, about 1 to 5 feet, the model was both laterally and longitudinally unstable. The lateral motion could be stabilized by use of the yaw damper so the longitudinal motion could be studied more carefully than was possible at the longer towline lengths.

The longitudinal motion of the model was an unstable short-period oscillation as indicated by figure 6. The theoretical results of both references 4 and 5 also indicate longitudinal instability for this tow condition. The pilot was unable to control the pitching motion of the model because the period of this motion was too short (about 1/2 second). This motion might be controllable in the case of the full-scale F-84E airplane for which the period of this oscillation would be about 2 seconds. It is suggested in reference 5 that the longitudinal stability of the parasite may be improved by reducing the cable tension by use of thrust.

Direct Coupling Tests

The model was very stable longitudinally for all the direct coupling configurations, but was unstable laterally in the basic configuration. These results are in agreement with the calculated stability presented in references 4 and 5. The experimental results for the various direct coupling configurations are shown in figure 7. This figure shows the effect of the following parameters on the uncontrolled rolling motions: mass distribution, spring restraint in roll, and damping in yaw. The pilot's comments on the controllability of the model for all the configurations covered in the tests are also presented in this figure. A detailed discussion of the effect of the various parameters on the lateral stability and controllability of the model is presented in the following paragraphs.

Effect of mass distribution.- The effect of increasing the rolling and yawing moments of inertia of the model (from loading condition I to II to III, table II) by adding weights at the wing tip can be seen by comparing the motions across the rows of figure 7. These flight records show that in all the conditions increasing the load at the wing tips caused the model to become less stable. For example, in the freely coupled case (no spring or artificial damper) and in the weak-spring-restraint case the instability of the oscillations increased as the load was increased. Similarly, in the strong-spring case and in the increased C_{n_r} case the oscillations which were stable for the light loading condition became unstable as the inertias were increased to the highest value.

The control ratings for the two spring conditions and for the increased C_{n_r} condition show that increasing the inertias made the model more difficult to control. For the two spring conditions the model could be controlled easily for the low inertia condition but for the high inertia condition it was difficult to control following large disturbances. With the yaw damper, control of the model was satisfactory for all three loading conditions but became less easy as the inertia increased.

Effect of spring restraint in roll.- The stabilizing effect of spring restraint in roll is shown in figure 7 by comparing the motions in each of the three loading conditions for the three amounts of spring restraint. For the lightly loaded condition (condition I, table II) the weak spring improved the lateral oscillation so that it was very mildly unstable and could be controlled by the pilot easily. Strong spring restraint resulted in a stable oscillation for this mass configuration.

For inertia condition II, table II, increasing the spring restraint made the oscillation less unstable and improved the controllability. The weak spring improved the behavior enough to permit the pilot to control the motion, but the oscillation was hard to stop when it was allowed to build up to a large amplitude. With the strong spring the lateral motions could be controlled easily even after large disturbances.

With the inertias increased further (condition III, table II) the model could be controlled when the strong spring was used. Small disturbances were easily controlled, but large disturbances or large amplitude oscillations were difficult to control.

Effect of C_{n_r}.- Figure 7 shows that an increase in the value of C_{n_r} to six times the normal value for the model improved the lateral stability of the model even more than the strong spring did. The model was unstable only for the highest inertia condition and even this instability was mild and the motions could be easily controlled by the pilot.

From this trend it appears likely that the stability of the F-84E will be a little better than that indicated by the test model without the yaw damper because the F-84E has somewhat greater damping in yaw.

Effect of spring restraint and C_{n_r}.- When the yaw damper and strong spring restraint in roll were used together the model was stable, even for the highest inertia condition (condition III, table II). Although the model was not tested at either of the more lightly loaded conditions for this restraint configuration, it is reasonable to conclude on the basis of the previous results that the stability would be even better for these loading conditions.

Effect of C_{l_p}.- Tests were also made to determine the effect of increasing the damping in roll to about twice the normal value for several mass and spring restraint conditions. The roll damper was found qualitatively to have no appreciable effect on the lateral stability and control characteristics of the model and, therefore, no systematic series of tests was made and no motions are presented. This result indicates that the effect of the small difference in the values of the damping-in-roll parameters for the test model and for the F-84E is negligible.

Effect of tow attachment location.- A few tests were made to determine the effect of tow attachment position on the stability and controllability of the model. Several cases in which the model was mildly unstable with the towline attached at the design attachment location were selected for this comparison. In one case attachment at the alternate location appeared to improve the stability slightly but the oscillation was still unstable. In the other case no difference in behavior was apparent.

SUMMARY OF RESULTS

As part of a study to determine the feasibility of using a combination of the Consolidated Vultee RB-36 and Republic F-84E airplanes for long-range high-speed reconnaissance (project FICON) an experimental investigation has been conducted in the free-flight tunnel to determine the stability and controllability of a parasite fighter airplane in several launching and retrieving configurations. The model used in these tests approximately represented a 0.07-scale model of the F-84E airplane. The results of this investigation may be summarized as follows:

1. For the towline tests there appeared to be two types of behavior depending on the towline length.

(a) At towline lengths of about 20 feet (full scale) the model was laterally unstable and uncontrollable. Neither a yaw damper which increased the damping in yaw to about six times the normal value, nor a roll damper which increased the damping in roll to about twice the normal value produced any appreciable improvement in the behavior of the model. A change in the towline attachment position from the design location to the alternate location also had no effect on the behavior of the model.

(b) At towline lengths of about 1 to 5 feet (full scale) the lateral oscillation was unstable but could be stabilized by use of the yaw damper. The longitudinal motion was an unstable short-period oscillation which could not be controlled by the pilot.

2. For the zero-towline-length case where the model was directly coupled to the strut with complete angular freedom, the following results were obtained:

(a) The longitudinal stability was good in all the configurations covered in the tests.

(b) The lateral oscillation of the model in the basic configuration was very unstable and uncontrollable, but the use of a yaw damper and/or spring restraint in roll improved the lateral stability. With the strong roll spring and the yaw damper used together, the lateral oscillation was stable for all the loading conditions covered in the tests. Increasing the load at the wing tips was found to have a destabilizing effect. Neither use of the roll damper nor the alternate attachment position resulted in any significant change in the lateral stability or controllability of the model.

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1. Tucker, Warren A., and Goodson, Kenneth W.: Tests of a 1/5-Scale Model of the Republic XP-84 Airplane (Army Project MX-578) in the Langley 300 MPH 7- by 10-Foot Tunnel. NACA MR L6F25, Army Air Forces, 1946.

2. Campbell, John P., and McKinney, Marion O.: Summary of Methods for Calculating Dynamic Lateral Stability and Response and for Estimating Lateral Stability Derivatives. NACA TN 2409, 1951.

3. Shortal, Joseph A., and Osterhout, Clayton J.: Preliminary Stability and Control Tests in the NACA Free-Flight Wind Tunnel and Correlation With Full-Scale Flight Tests. NACA TN 810, 1941.

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5. Stern, M.: Dynamic Stability Analysis of Parasite Fighter for Project FICON. Rep. No. EAR-250, Republic Aviation Corp., June 4, 1951. N-13816

TABLE I

COMPARISON OF AERODYNAMIC PARAMETERS OF THE F-84E

AIRPLANE AND OF THE TEST MODEL

Parameter	F-84E	Test model
C_L	0.55 to 0.7	0.55 to 0.7
C_D	0.055	0.05
$\partial C_m/\partial C_L$	0.075	0.065
C_{l_β}	-0.0023	-0.0020
C_{n_β}	0.0022	0.0017
C_{Y_β}	-0.0115	-0.009
C_{l_p}	-0.38	-0.44 and -0.85[a]
C_{l_r}	0.298	0.285
C_{n_p}	-0.022	-0.019
C_{n_r}	-0.187	-0.125 and -0.77[b]

[a]With roll damper.

[b]With yaw damper.

TABLE II

COMPARISON OF THE MASS CHARACTERISTICS OF THE F-84E

AIRPLANE AND THE TEST MODEL (SCALED UP)

Parameter	F-84E		Test model		
	Wing-tip tanks		Loading condition		
	Off	On	I	II	III
Gross weight, lb	12,256	18,151	13,700	16,200	18,150
I_X, slug-ft^2	9,750	52,300	9,030	39,700	76,600
I_Y, slug-ft^2	17,740	20,000	25,600	26,000	26,200
I_Z, slug-ft^2	26,500	71,000	30,600	60,100	97,000

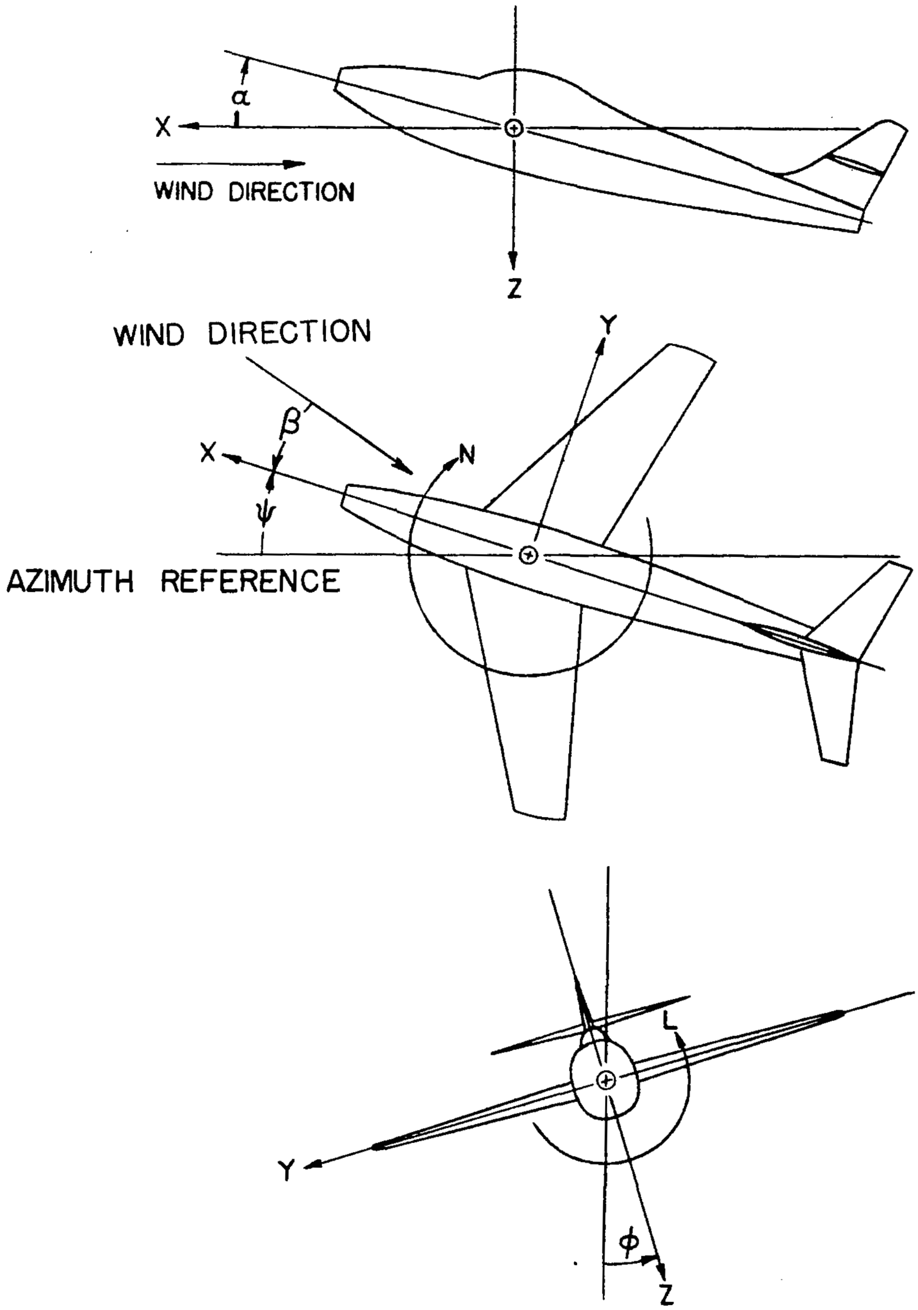

Figure 1.- The stability system of axes. Arrows indicate positive directions of moments, forces, and angles. This system of axes is defined as an orthogonal system having the origin at the center of gravity and in which the Z-axis is in the plane of symmetry and perpendicular to the relative wind, the X-axis is in the plane of symmetry and perpendicular to the Z-axis, and the Y-axis is perpendicular to the plane of symmetry. At a constant angle of attack, these axes are fixed in the airplane.

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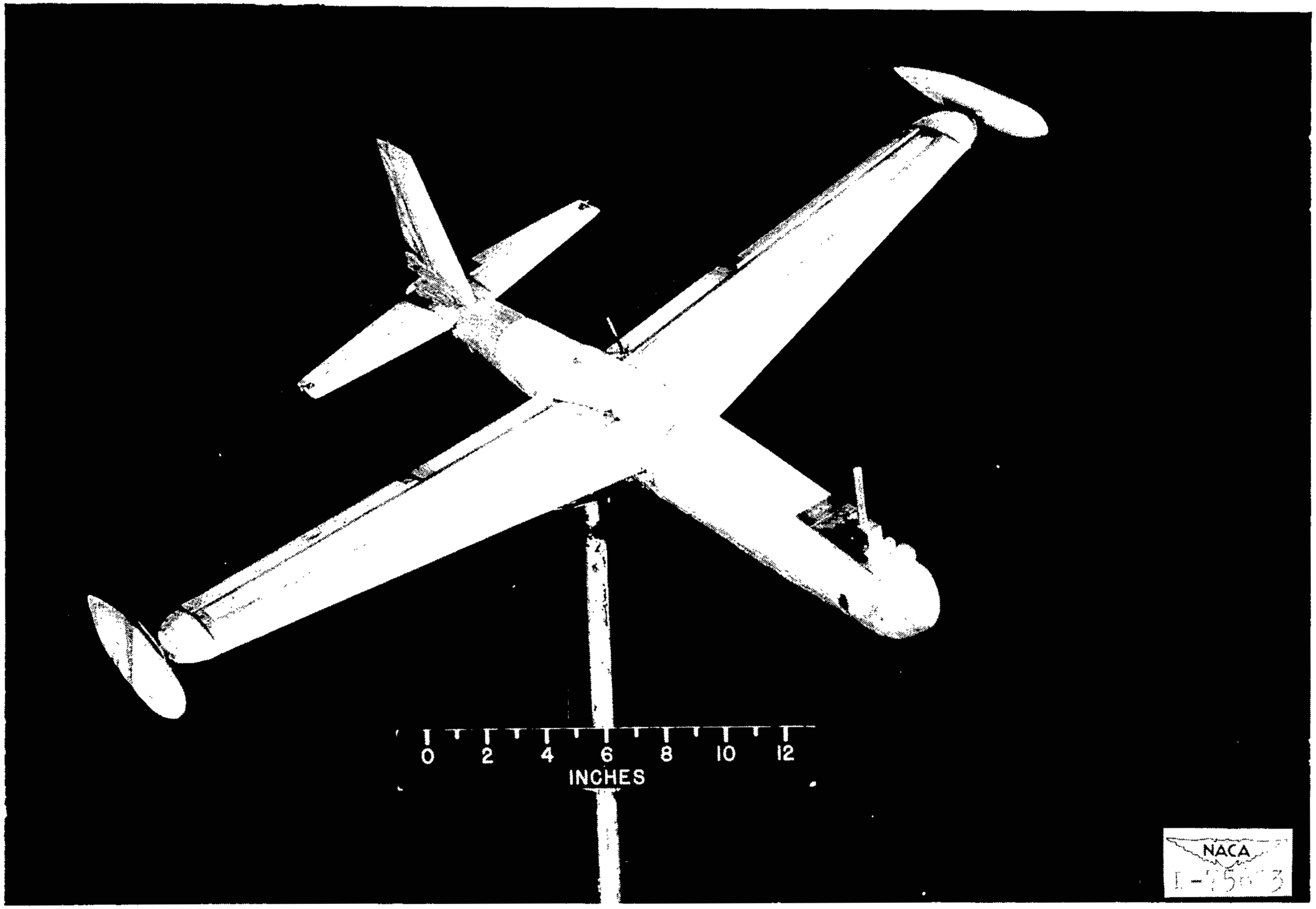

Figure 2.- Photograph of the model used in the tests.

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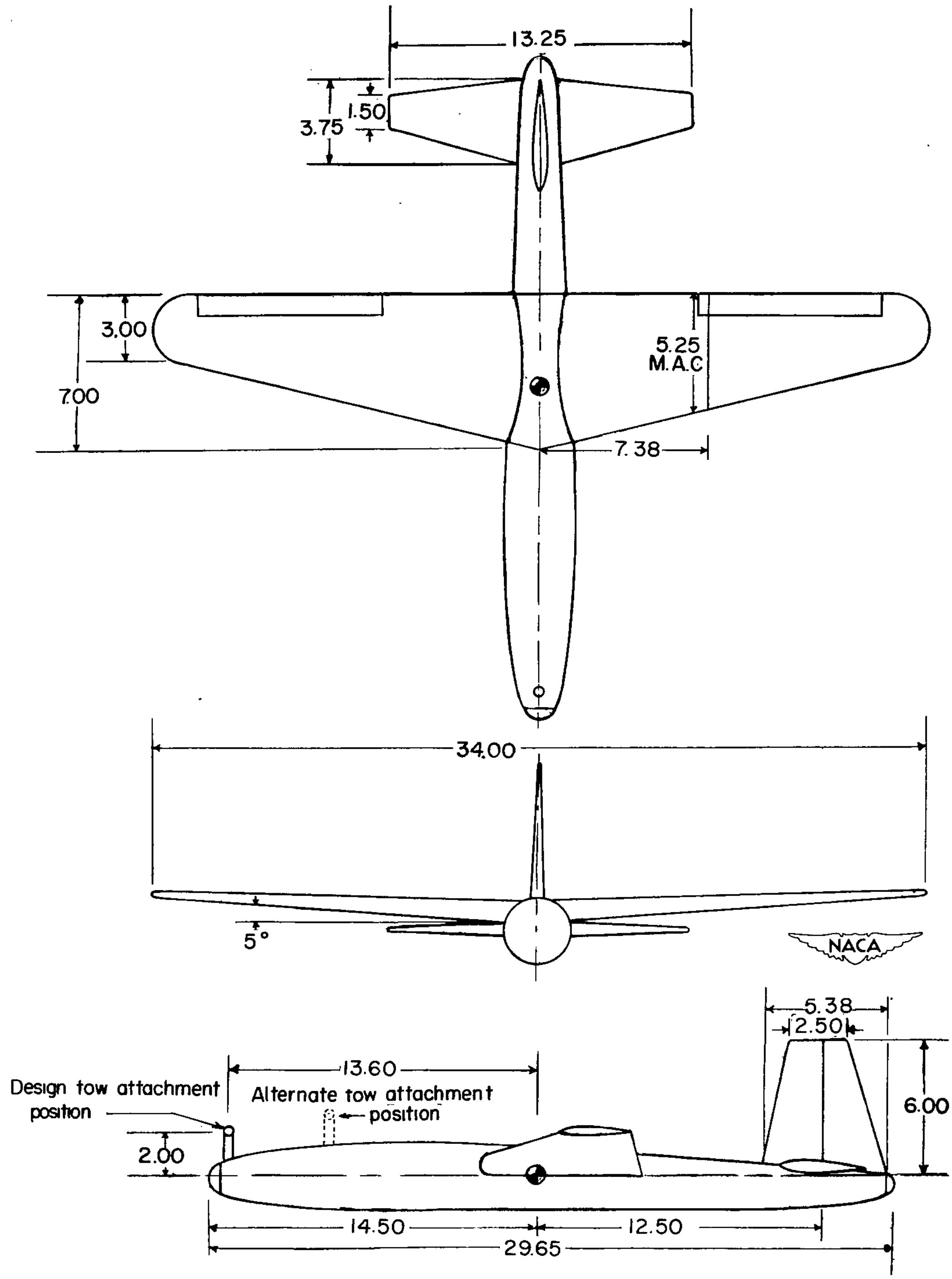
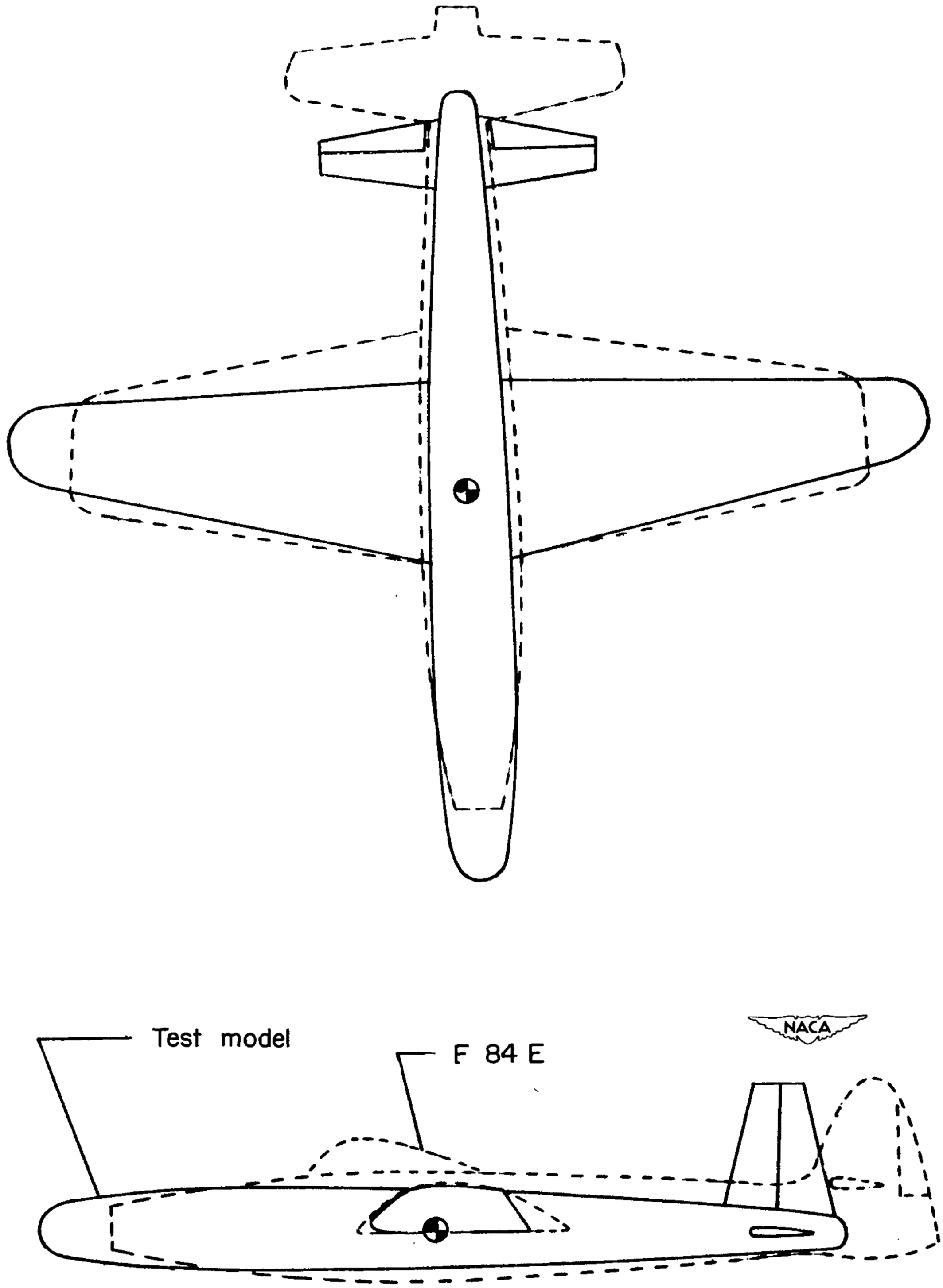


(a) Model used in tests.

Figure 3.- Model used in tests and comparison with 0.07-scale model of F-84E airplane.



(b) Comparison of the test model with 0.07-scale model of F-84E airplane.

Figure 3.- Concluded.

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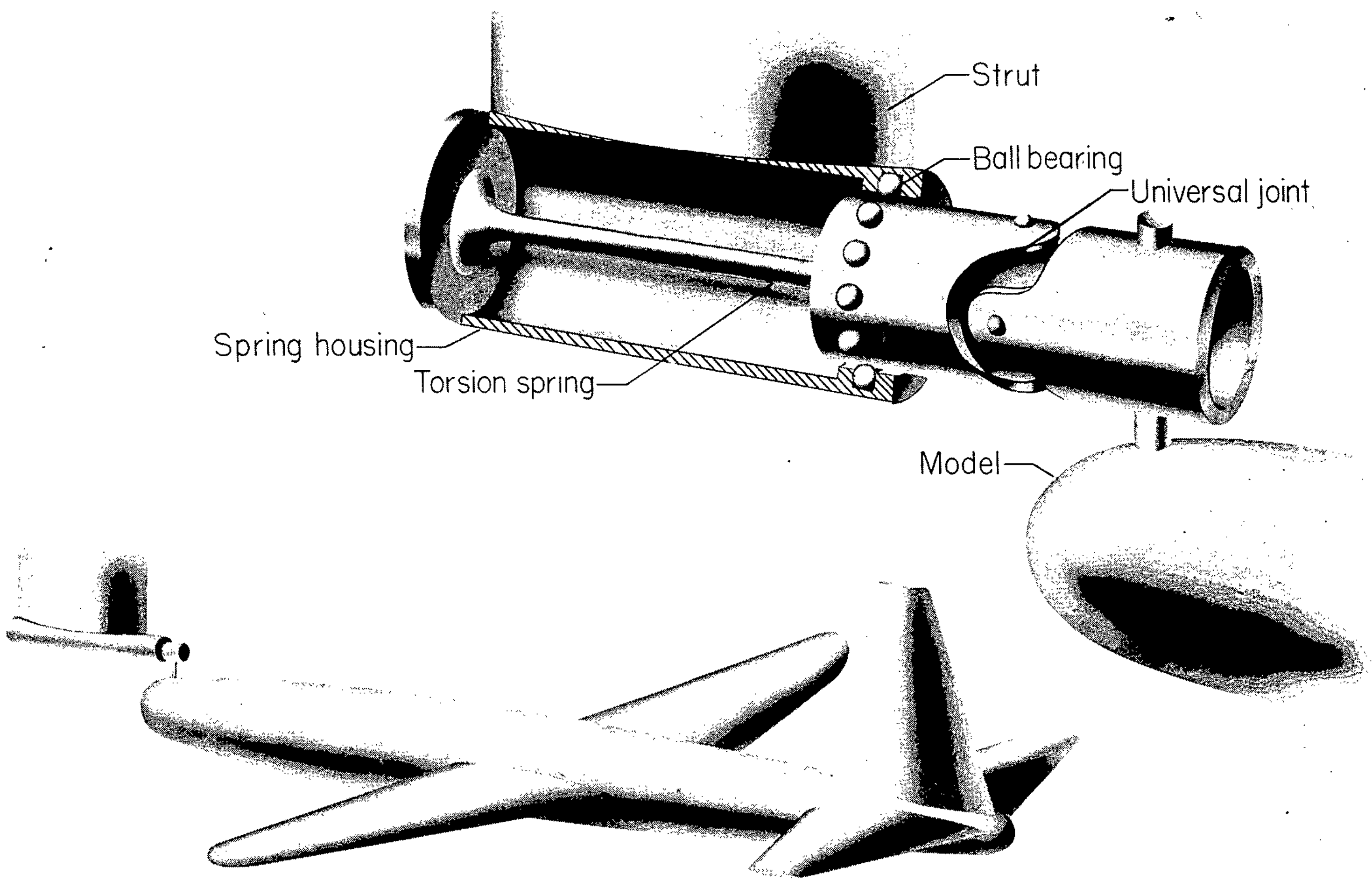

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Figure 4.- Sketch of model on tow in tunnel showing direct coupling details.

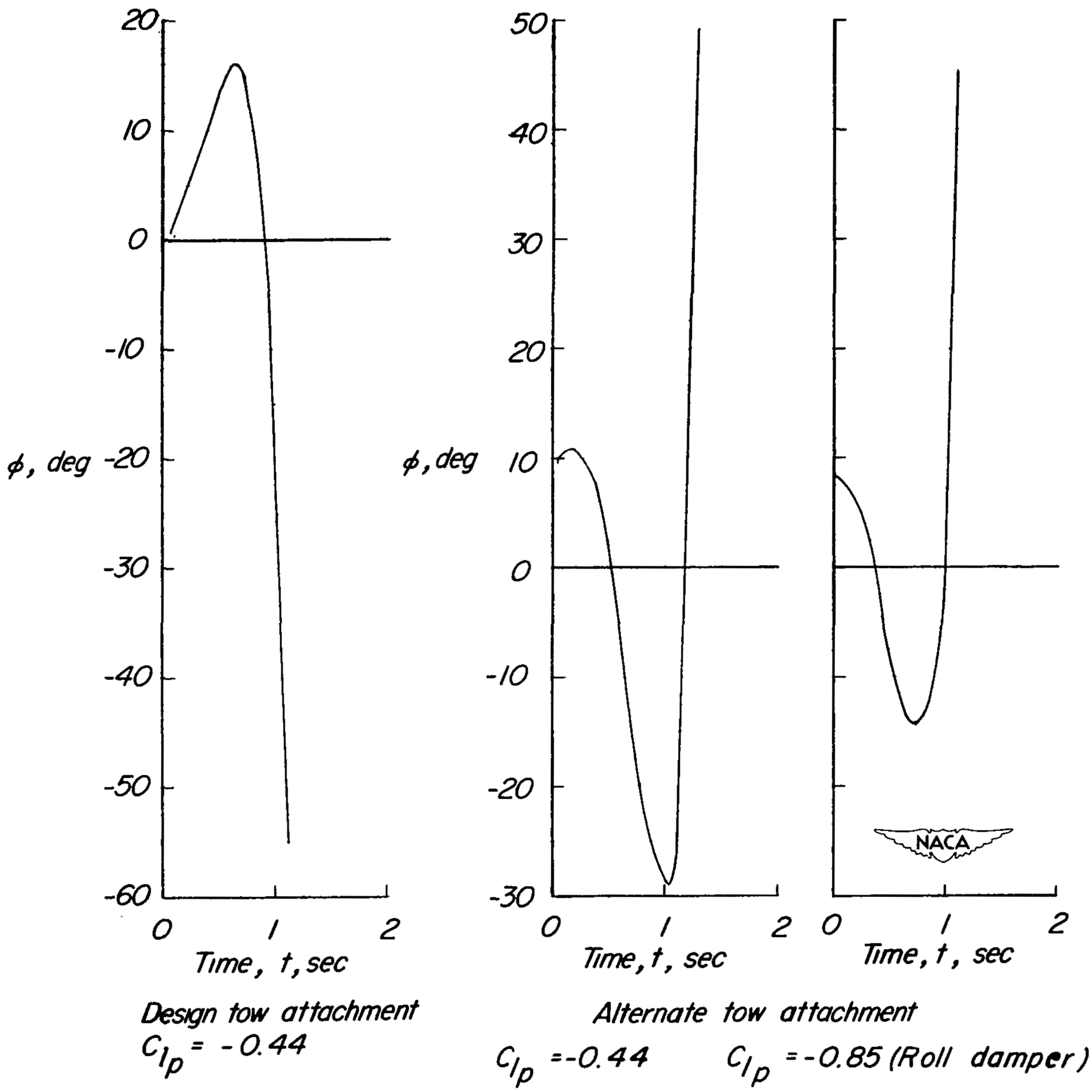

Figure 5.- Uncontrolled rolling motions of model towed by a towline corresponding to 20 feet, full scale.

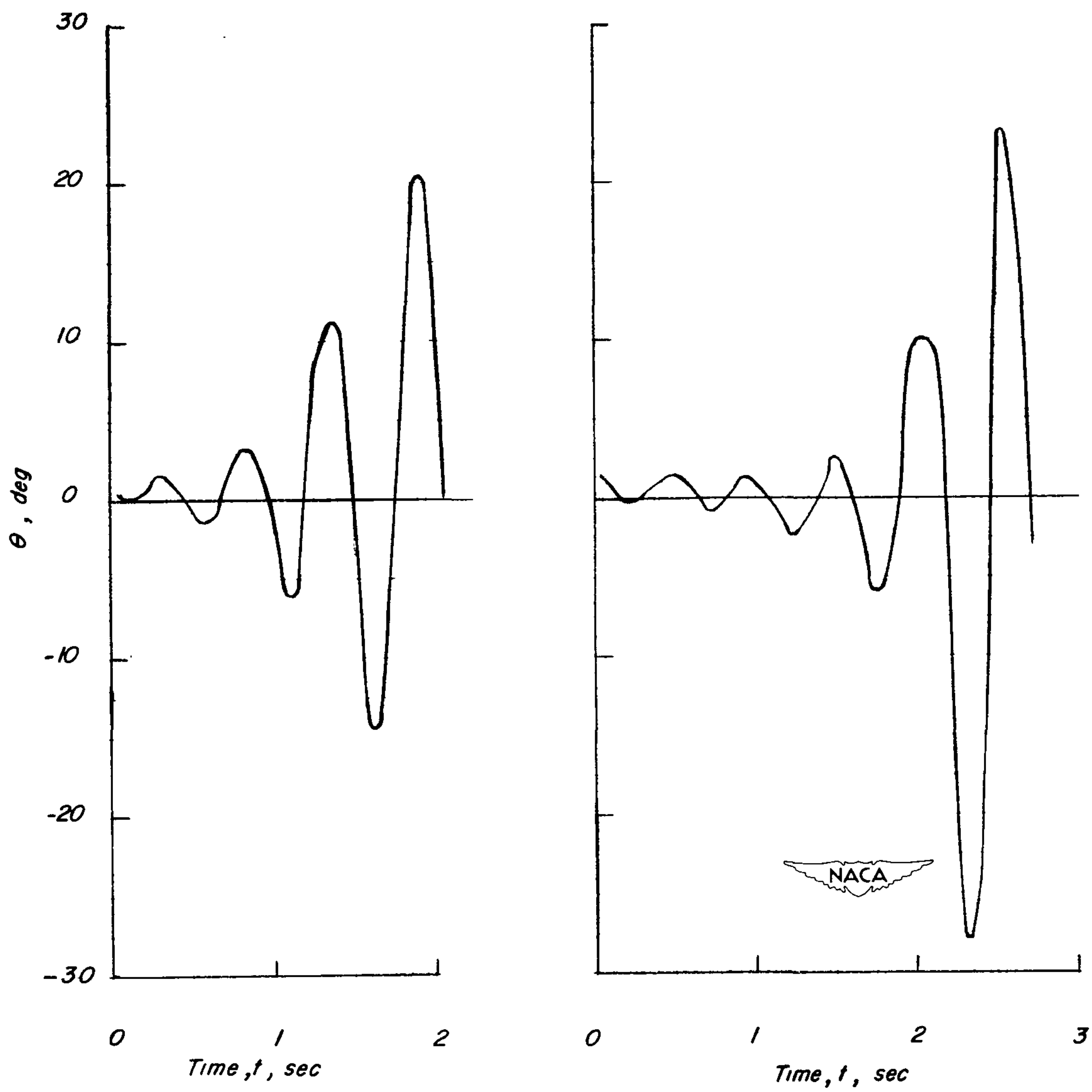

Figure 6.- Uncontrolled pitching motions of model towed by a towline corresponding to 5 feet, full scale.

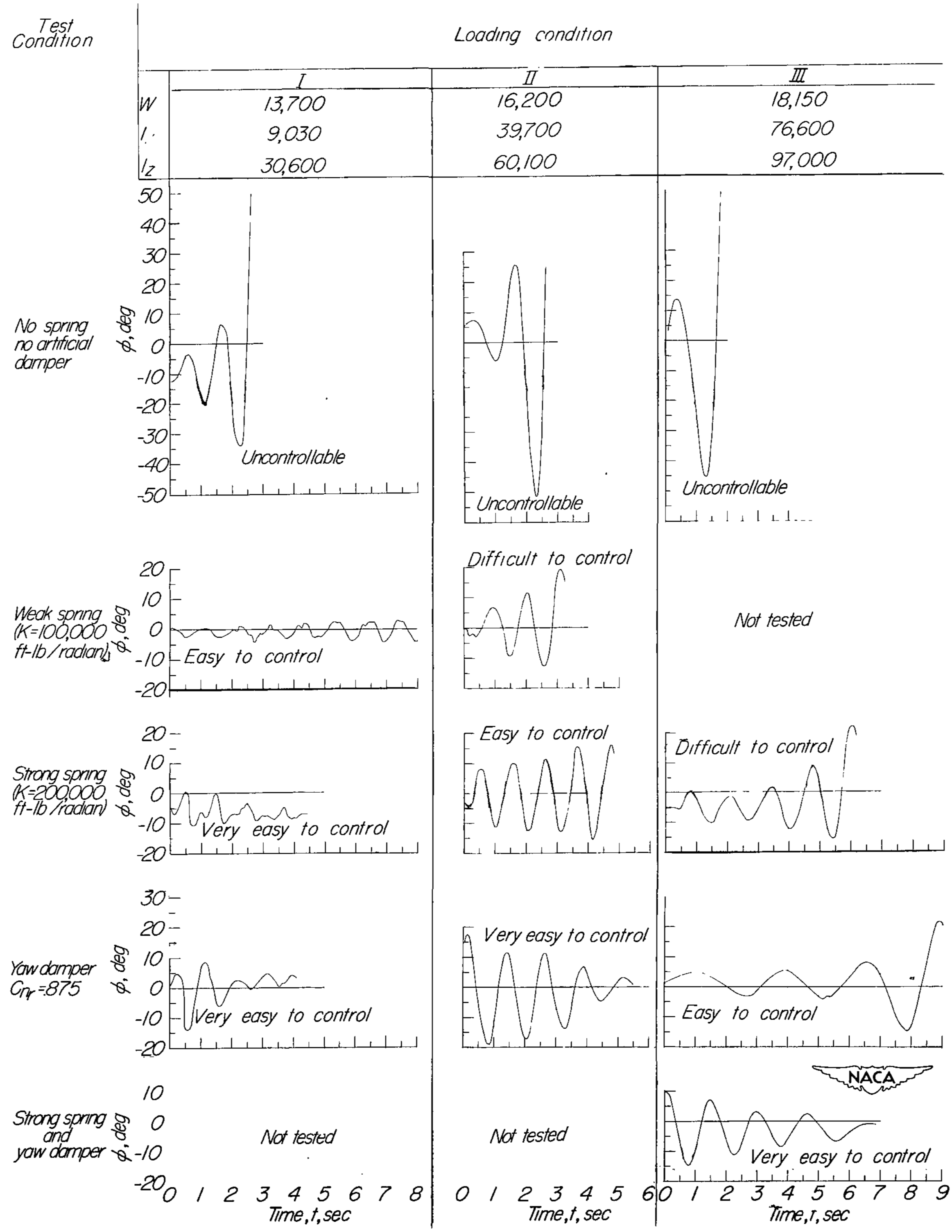

Figure 7.- Uncontrolled rolling motions and comments on controllability of model in various direct-coupling configurations.